Case Study on Structural Performance of various Bracings in Steel Frame of Buildings

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Abstract: Steel framed buildings resist lateral loads as well as the gravity loads. Components of the buildings are subjected to high stresses due to lateral loads making the whole structure sway and giving rise to lateral displacements. The research carried out highlights the modelling and analysis of a one-storey industrial steel frame in ETABS incorporating various types of bracing systems namely diagonal, K and X-bracing and eventually determining the structural performance of steel frames with different bracings. Initially, a bare frame was modelled with 6m, 7.5m and 10m bay lengths followed by the bracings being incorporated in an alternative system. For the seismic analysis, linear static analysis was performed and the performance matrices chosen were maximum storey displacement, time period and base shear. The results exhibited that the X-bracing was the most effective type of bracing system.

Keywords: Bracing, Steel frames, displacement, time period, base shear

Introduction

Steel framed industrial building refers to any factory or establishment in which goods or materials are manufactured, assembled, fabricated or stored. Industrial buildings are usually constructed with steel because steel enables large spaces to be constructed and can be easily modified, extended and recycled anytime without its loss of strength. Bhutan on the other hand lies in the most active seismic zone that is zone V. Earthquakes are the most imminent hazard in Bhutan considering the location of the country and the past earthquake records, so it becomes crucial to building structures which can resist earthquakes of higher magnitudes. A braced frame in a building is commonly used to resist lateral forces like wind and earthquakes. It is commonly used owing to its simplicity to analyze, it is economical and provides stability and makes the structure stiffer (Adin et al., 2016).

A braced frame is of two types namely, concentric bracings and eccentric bracings. Concentric bracings are those bracings which are connected to the joint of a frame and are usually adopted to increase the stiffness of the structure and reduce lateral displacements. Eccentric bracings are those bracing systems, where the ends of braces are connected at a certain distance from the joint of a frame.

Literature Review

As per Zaveri et al. (2015), study on the effectiveness of steel bracing systems, the structure must be designed in such a way that it performs well under the seismic loads. The steel bracings were introduced in the structural system whereby the shear capacity of the structure was increased. Di Sarno et al. (2008) examined the seismic response of stainless-steel braced frames. The authors studied the feasibility of the application of stainless steel (SS) in the design of the braced frames with both concentrically (CBFs) and eccentrically (EBFs) braced. It was concluded that the use of the diagonal bracing increases the overall strength of the lateral resisting system. Khusru & Tafheem (2013) examined the behaviour of six-storied steel buildings incorporating both concentric and eccentric bracing patterns in ETABs 9.6.0 software. It was found that the concentric X bracing and eccentric bracing reduces more lateral displacement and also provide greater stiffness to the structure. Another study was conducted using modal analysis of braced and unbraced steel frames to determine the dynamic characteristics and also to determine structural vibration characteristics. A comparative study of braced and unbraced frames based on the modal analysis was carried out. In the comparisons, it was found that concentrically braced frames exhibit the best performance (Mahmood, 2020).

Objective of the study

The main objective of the research is to compare the performance of different bracings in industrial steel framed buildings and identify the most effective bracing system for a steel framed building. The study aims to model an industrial steel framed building, followed by the identification and incorporation of different steel bracings. This study will also study the effect of different bay lengths on the structural performance of the buildings based on parameters like maximum lateral displacement, time period, base shear and demand capacity ratio.

Methodology

After the literature review and based on the aim and objectives of the research, the following methodology shown in Figure 1 was developed and adopted.

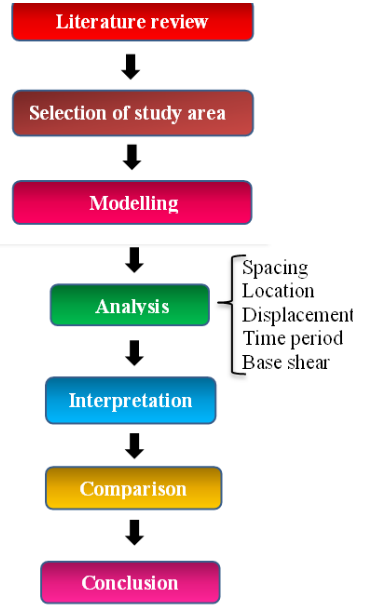


Figure 1. Research Methodology

Study Area

Pasakha was been chosen as the study area which is located 14 kilometers away from Phuentsholing town. The area comprises in total of 26 numbers of factories owing to different manufacturing products and functions. It was chosen based on the location, availability of raw materials, labour and population density. Few site visits were made for data collection and modelling works, on the existing industrial buildings.

Figure 2. Industrial building of Bhutan Concast Steel Private Limited, Pasakha

The overall dimensions of the building are 60m in length and 30m in breadth. A 2-dimensional model along with the location of the columns in red was created in AutoCAD and the plan of the building is shown in Figure 3.

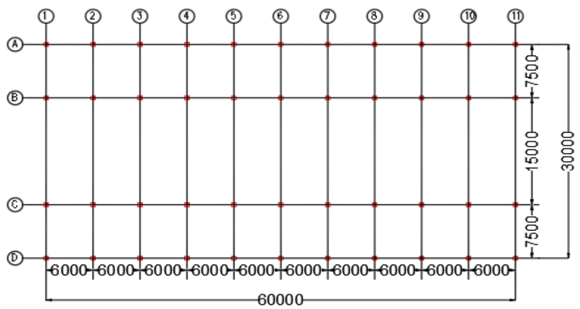


Figure 3. Building Plan (All dimensions in mm)

Data Modelling and Analysis

The truss configuration suitable for the building was Pratt truss. The roof trusses are divided based on the spacing kept between the columns.

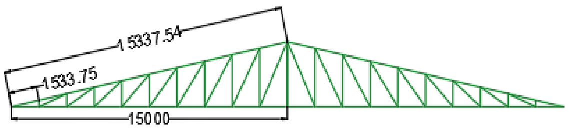


Figure 4. Pratt Truss (All dimensions in mm)

- Span of the truss= 30m
- Centre to centre distance= 6 m
- Height of the eave above the ground level= 6 m

The dead load, live load and wind load acting on the purlin and truss was calculated as per IS code 875 Part I, II and III.

The modelling details include a mathematical representation of the 3-D model which helps to visualize the virtual building. The planning of the steel structure was then followed by modelling. Modelling for the industrial structure incorporating different bracings was carried out altering the spaces and different types of bracings. The table below shows the modelling details.

Table 1. Modelling Details

Parameters	Description
Building dimension	60m×30m
Storey height	3.2m
Bay length	6m, 7m, 10m

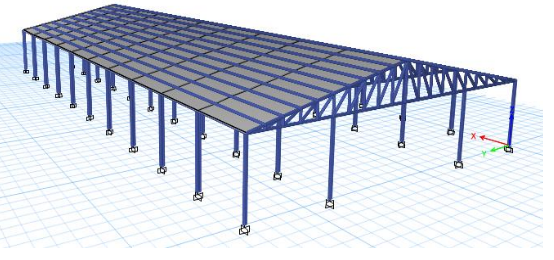
Rafter and main tie	ISNB80M
Struts	ISNB65M
Purlins	ISNB65M
Grade of steel	Fe450
Seismic zone	V
Type of soil	Type II medium
Seismic zone factor	0.36
Response reduction factor	5
Importance Factor	1

Mass source is the mass of the structure consisting of self-weight and additional gravity loads. Mass source should be defined to perform the seismic analysis so as to calculate the base shear of the structure. As per IS1893:2002 Part I, the mass source for structure containing imposed load less than 3 kN/m^2 should be 25% of the imposed load.

Other criteria for the seismic load analysis is model analysis. Model analysis gives us an idea on different shape a structure can take up during vibration and the shapes are known as mode shapes. In the analysis, the sum total of model masses should at least be 90 percent of the total seismic mass. The column sections were taken after repetitive iterations.

The column sections used for the 6m bay length: C1:ISMB200, C2: ISMB300, C3: ISMB200, C4: ISMB25. The column sections used for 7.5m bay length are C1:ISMB200, C2: ISMB300, C3: ISMB300, C4: ISMB300. The bracing angle sections for 6m and 7.5m bay length were of ISA80× 80×10. The column sections used for 10m bay length are C1:ISMB200, C2: ISMB300, C3: ISMB300, C4: ISMB300. The bracing angle sections for 10m bay length were of ISA110× 110×10 and ISA100× 100×10.

The following figures show the bare frame (base design) and bare frame with diagonal, K and X-bracings.



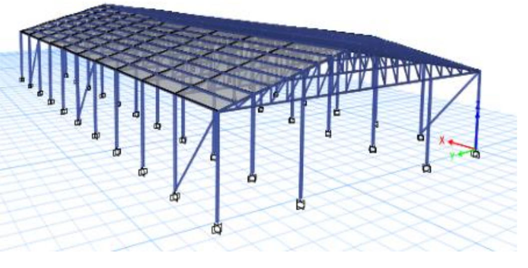


Figure 5. (a) Bare frame, (b) Diagonal braced frame

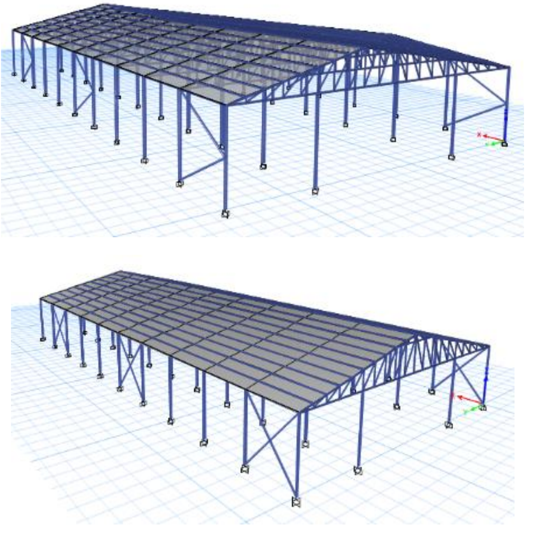


Figure 6. (a) K-braced frame, (b) X-braced frame

Analysis of the results showed that it was most effective when the bracings were placed at alternate locations. The result analysis is given under the result and discussion section.

Design check

While carrying out a design check, the main parameter considered was the demand capacity ratio. Demand capacity ratio is the measure of demand on the member against its capacity. And it should always be less than 1.0 so that the members would not be subjected to loads beyond the carrying capacity. After modelling the structures, analysis was done and the design check was carried out for all the models. Sections were reduced based on the demand capacity ratio limit. A sample of design check model is as given below.

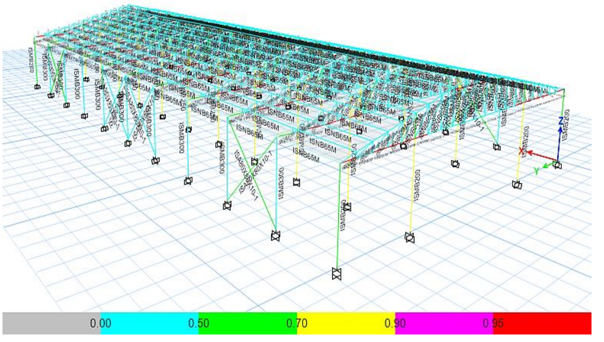


Figure 7. Designed Model

Results and Discussion

The results were obtained after the analysis and design check was carried out. The parameters adopted for the analysis are storey displacement, time period and base shear. Result analysis for 6m, 7.5m and 10m bay lengths are summarized in the following tables.

Table 2. Displacement results (all values in mm)

Types of bracing	6m	7.5m	10m
Bare frame	34.48	37.98	44.03
Diagonal	31.94	35.48	42.21
K-bracing	32.25	35.72	42.63
X-bracing	30.06	34.89	40.01

Table 3. Time period results (all values in secs)

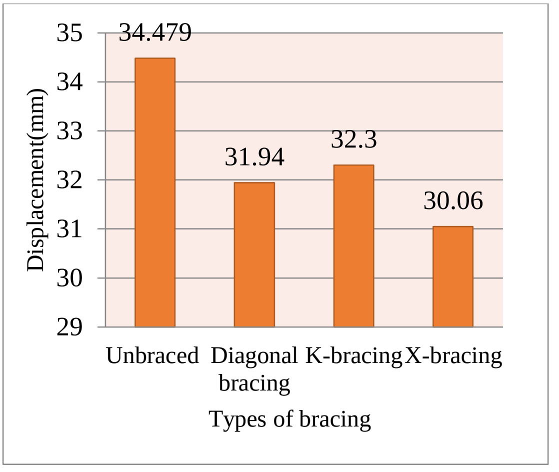
Types of bracing	6m	7.5m	10m
Bare frame	2.06	2.18	2.47
Diagonal	1.797	1.99	2.35
K-bracing	1.798	1.98	2.41
X-bracing	1.796	1.97	2.05

Table 4. Base shear results (all values in kN)

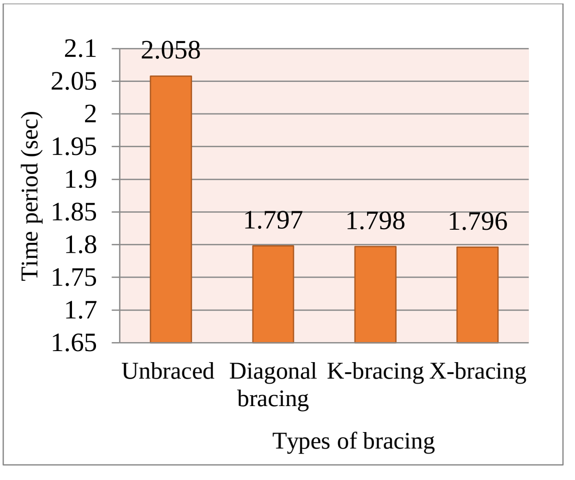
Types of bracing	6m	7.5m	10m
Bare frame	15.6	14.18	11.89
Diagonal	17.75	15.98	12.72
K-bracing	17.83	15.64	12.01
X-bracing	18.10	16.18	12.89

For all the bay lengths, the displacement and time period were less for X-bracing. The base shear was greater as compared to the diagonal and K-bracing. For all the three bay lengths, X-bracing was the most effective bracing system for the parameters considered.

The graphs shown below are the results for bracing in alternate location for base design.



(a)



(b)

Figure 8. (a) Displacement and (b) Time Period Results

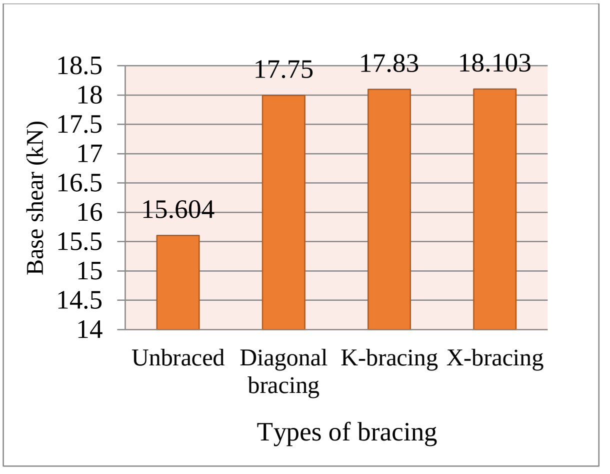


Figure 9. Base Shear Results

For all three types of bracing, the displacement and time period are less and the base shear is more when placed in alternate bays. Alternate location was found to be the most effective location to place the bracings as per the findings. The indices also clearly indicated improvement in the structural performance of the steel framed buildings.

Conclusion

The research compares the effectiveness of diagonal, K-bracing and X-bracing in one storey industrial steel framed building. The comparison was done for different bracing systems when placed in different bay lengths such as 6m, 7.5m and 10m at alternate locations. It was concluded that the X-bracing was the most effective bracing system for all the bay lengths.

The results were plotted in the form of graph for their lateral displacement, time period and base shear. It was found that the most effective way to place the bracings was in alternate bays.

Conflict for interest: The authors declare no conflict of interest.

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